RESEARCH ARTICLE

Discounting for Money, Food, and Sex, over the Menstrual Cycle

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Abstract

Sexual desire, physical activity, economic choices and other behaviours fluctuate over the menstrual cycle. However, we have an incomplete understanding of how preferences for smaller sooner or larger later rewards (known as delay discounting) change over the menstrual cycle. In this pre-registered, cross-sectional study, Bayesian linear and quadratic binomial regression analyses provide compelling evidence that delay discounting does change over the menstrual cycle. Data from 203 naturally cycling women show increased discounting (preference for more immediate rewards) mid-cycle, which is at least partially driven by changes in fertility. This study provides evidence for a robust and broad-spectrum increase in delay discounting (Cohen's h ranging from 0.1 to 0.4) around the fertile point in the menstrual cycle across multiple commodities (money, food, and sex). We also show, for the first time, that discounting changes over the menstrual cycle in a pseudo-control group of 99 women on hormonal contraception. Interestingly, such women increase their discounting of sex toward the end of the menstrual phase — possibly reflecting a prioritisation of bonding-related sexual activity before menstrual onset.

Keywords Menstrual cycle · Women's health · Delay discounting · Time preference · Hormonal contraception

Introduction

A wide variety of behaviours of naturally cycling females change over the menstrual phase. They experience higher sexual desire during ovulation (Gangestad et al., 2005), are more physically active (Fessler, 2003), and show an increase in flirting (Cantú et al., 2014) and competitiveness (Durante et al., 2014). Moreover, in the fertile window, females tend to wear more provocative clothes (Haselton et al., 2007) and display stronger preference for males with characteristics associated with genetic quality, such as symmetry and masculinity (Gildersleeve et al., 2014).

This paper focuses upon how delay discounting (the preference towards either smaller sooner rewards versus larger later rewards) changes over the menstrual cycle. The first study to examine this in naturally cycling women showed that mid-cycle, women displayed *lower* preference for immediate hypothetical monetary rewards (Smith et al., 2014).

That is, around peak fertility, preferences would shift away from short-term rewards toward larger later monetary rewards. A cross-sectional study of naturally cycling women was conducted by Lucas and Koff (2017), but their data showed the exact opposite pattern. Mid-cycle women around peak fertility displayed *stronger* preference for immediate hypothetical monetary rewards. The present study aims to resolve these conflicting findings and to expand our knowledge in both naturally cycling women (NC) and those on hormonal contraception (HC).

Phases of the Menstrual Cycle

For naturally cycling (NC) females, a typical menstrual cycle comprises two predominant phases, the follicular phase (FP) and the luteal phase (LP; see Table 1). The FP starts at day 1 of the cycle (the first day of menses) and varies in length between 1 and 2 weeks, typically. The FP can also be broken into two phases, early follicular (EF) and late follicular (LF). In the EF, sex hormone levels are relatively low and stable; in the LF, the sex hormone levels rise before ovulation occurs. Females are fertile from the day of ovulation (LF) for up to 2 days after making this the fertile part of the menstrual cycle. Ovulation is the day that the egg is released and marks the end of the FP

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Table 1 Characteristics of menstrual cycle phases

Phase	Days (approximately)	Sex hormone levels
Early FP	1–7	Oestrogens: low, stable Progesterone: low, stable Follicle-stimulating hormone: low, stable Luteinizing hormone: low, stable
Late FP	7–13	Oestrogens: increases, peaks Progesterone: low, stable Follicle-stimulating hormone: increases, peaks Luteinizing hormone: increases, peaks
Ovulation	14	Oestrogens: decreases Progesterone: low, stable Follicle-stimulating hormone: low, stable Luteinizing hormone: decreases
LP	15–28	Oestrogens: increases, decreases Progesterone: increases, peaks, decreases Follicle-stimulating hormone: decreases, low, stable Luteinizing hormone: decreases, low, stable

(and the LF subphase of the FP). Then, the LP begins with sex hormone (LH, FSH, and oestrogen) levels decreasing sharply before oestrogens and progesterone rise and fall over the phase, which is approximately 2 weeks in length (Hampson, 2020).

Why Might Behaviour Vary over the Menstrual Cycle?

Evolutionary accounts offer an approach with the potential to explain why (rather than just how) behaviours may change as they do. Humans and other primates are unique among the animal kingdom for having evolved control over sexual behaviours, such that we can moderate these behaviours in conjunction with psychological impulses (Wallen & Zehr, 2004). Fluctuating hormones, however, still influence behaviour in our species and in our primate relatives. The ovulatory shift hypothesis (Thornhill & Gangestad, 2008) states that alterations in women's motives, thoughts, and behaviours across the menstrual cycle are based on hormonal changes. Specifically, female behaviours during the fertile window (ovulation) are motivated by increased conception opportunity (Gildersleeve et al., 2014). Shifts in time preference towards immediate rewards during the most fertile window could help acquire essential supplies to improve attractiveness, reproductive success, and outperform potential rivals. Research on economic choice behaviours support this view: During peak fertility, women tend to spend more money on clothing (Saad & Stenstrom, 2012), pick products that boost appearance (Durante et al., 2011; Haselton et al., 2007), withdraw more money from attractive rather than less attractive females in a competitive setting (Lucas & Koff, 2013), and seek to obtain sources that elevate their social status (Durante et al., 2014).

The Present Study

A variety of behaviours fluctuate over the menstrual cycle, but in terms of discounting we have conflicting findings between Smith et al. (2014) and Lucas and Koff (2017). Our goal is to move towards resolving this uncertainty by conducting a cross-sectional study of women, assessing their temporal discounting. We make three important advances in our approach. Firstly, we not only characterise discounting in NC women, but also use women on hormonal contraception (HC) as a pseudo-control group. This is a relatively rare practice, but we believe it is important. If behaviours change due to changes in gonadal hormone levels, HC would interrupt this cyclic variation (Erol & Karpyak, 2015), which may subsequently affect behaviour (Warren et al., 2021). Secondly, rather than focussing only on preference for monetary rewards, we also evaluate discounting for food and sex. There is convincing evidence that time and risk preferences are sensitive to the kind of reward being considered (Charlton & Fantino, 2008; Rosati & Hare, 2016), so characterising any changes in discounting for food, money, and sex can help constrain theorising. Thirdly, while it is common to examine the menstrual phase categorically (e.g. EF, LF, LP), this approach discards temporal information which may help characterise changes in discounting over the menstrual cycle. We analyse discounting behaviour as a function of both categorical menstrual phase *and* by the continuous measure of days since menstrual onset.

We pose the following research questions: (1) Does cycle phase (EF, LF, LP) influence delay discounting across food, sex, and money commodities in NC women; (2) Does discounting vary non-linearly over the menstrual cycle, and does that differ by group (NC/HC) for each of the 3 commodities; (3) Does discounting vary linearly as

a function of fertility and group (NC/HC) for each of the 3 commodities?

Methods

Participants

We used the Gorilla Experiment Builder (www.gorilla.sc) to create and host our questionnaire (Anwyl-Irvine et al., 2020) and recruited 413 menstruating individuals over 18 years of age through social media posts. It is likely that participants were intrinsically motivated to provide accurate responses as the study was not incentivised — nevertheless, we applied strict (pre-registered) exclusion criteria. A total of 13 participants failed 1 or more of 5 attention checks and were excluded. A further 6 were excluded who indicated they were pregnant. Forty-three participants were excluded for indicating "totally irregular" menstrual cycle lengths, defined as more than 7 days difference. Finally, 21 participants were excluded for having cycle lengths of greater than 40 days (*Periods and Fertility in the Menstrual Cycle—NHS*, 2019). This resulted in a total of 330 participants after our pre-registered exclusion criteria. We applied additional exclusion criteria resulting in removal of 25 participants whose days since menstrual onset measure was invalid (negative), or greater than 40 days. This was higher than expected because days since menstrual onset was calculated from the data of questionnaire completion and date of last menstruation — the latter contained dates that were unclear or very far in the past. We also recorded height and weight for a different hypothesis not examined in this study, but we used this data to remove 3 outlier participants with weight less than 40 kg. The final dataset contained 302 participants who were grouped into naturally cycling (NC) or hormonal contraception (HC) groups using pre-registered criteria. We categorised 203 participants into the NC group based on responding "no" when asked if they were on hormonal contraception. We categorised 99 participants into the HC group who specified their use of hormonal contraception — the type of hormonal contraception was not measured.

Procedure

The study received ethical approval from the University Research Ethics Committee of the University of Dundee. The study, measures, exclusion criteria, and analyses were pre-registered to the Open Science Framework at https://osf.io/vwr6s/. The questionnaire consisted of three sections: the demographic information, menstrual cycle details, and three independent tasks to investigate delay discounting behaviours for money, food, and sex, respectively. A total of 5 attention check questions were interspersed throughout the questionnaire.

Measures

Participants were asked a range of questions: age, has your body menstruated in the last 60 days (yes/no), gender (Female, Male, Non-binary, prefer not to say, other), height, weight, ethnicity (Asian, Black/African/Caribbean, Mixed/Multiple ethnic groups, Caucasian/White, Prefer not to say), sexual orientation (Asexual, Bisexual, Homosexual/Gay/Lesbian, Heterosexual/Straight, Questioning or unsure, Prefer not to say), relationship status (single, casual, serious, married), and relationship type (monogamous, polygynous, polyamorous, open relationship).

Further questions were asked relating to the menstrual cycle, hormonal contraception, and other hormone-related factors: (1) Regularity in menstrual cycle length (Perfectly regular (the same length between cycles), Regular (2–4-day difference), Irregular (5–7-day difference), Totally irregular (more than 7-day difference); (2) Length of menstrual cycle (days); (3) Days since menstrual onset — calculated by date of last onset minus questionnaire completion date; (4) Tracking method (tracking app, calendar, temperature check, cervical mucus observation, no method, other); (5) Contraception in last 3 months (yes/no); (6) Contraception type (hormonal/non-hormonal/not applicable); (7) Are you taking hormonal medication (other than contraception) which interferes with menstruation?; (8) Have children (yes/no); (9) Pregnant or breastfeeding (yes/no); (10) Planning on pregnancy in next 6 months (yes/no).

Estimation of Fertility

Fertility was estimated using the lookup table method of Wilcox et al. (2001) and is computed from the day of cycle for those classified as having regular vs irregular cycle lengths. This fertility measure provides a probability of clinical pregnancy following a single act of unprotected intercourse.

Discounting Tasks

Delay discounting tasks were created by applying an elicitation by the multiple price list approach (Andersen et al., 2006). Raw response data was scored simply as the number of immediate choices.

Discounting of Money Participants made a series of choices between immediate amounts of money now or a larger amount of money in the future e.g. "Would you prefer £95 now or £100 in 1 day?" The larger amount of money was always £100. There were 11 levels of immediate rewards £[95, 90, 80, 70, 60, 50, 40, 30, 20, 10, 5], and all were presented simultaneously in a list in descending order against the larger amount of money in the X days in the future.

There were 6 levels of delay until the future reward [1, 2, 7, 30, 180, 365] days. After making all the choices, 11 choices for the first delay (1 day), the next list of choices was presented where the identical other than the delay would be incremented to the next level.

Discounting of Food The same basic approach was taken, but participants made a series of choices between immediate amounts of food now or a larger amount of food in the future e.g. "Would you prefer 5 bites of food now or 10 bites in 1 h?" The larger reward was always 10 bites. There were 9 levels of immediate rewards [9, 8, 7, 6, 5, 4, 3, 2, 1] bites, and all were presented simultaneously in a list in descending order against 10 bites in the future. There were 6 levels of delay until the future reward [1, 2, 4, 6, 8, 10] hours. After the food discounting task, two further questions were asked: "When did you last eat?" (less than 10 min ago, 10–30 min ago, 30 min–1 h ago, 1–2 h ago, more than 2 h ago) and "What kind of food were you thinking about?" (healthy food, sweet food, fatty food, other — please specify); however, these responses were not analysed.

Discounting of Sex Participants selected between hypothetical immediate lower-quality sex or delayed high-quality sex. Quality was indicated by points out of 10, so an example question would be "Would you prefer 6/10 sexual activity now or 10/10 in 1 h?". The larger reward was always 10/10 sexual activity. There were 9 levels of immediate rewards [9, 8, 7, 6, 5, 4, 3, 2, 1] out of 10, and all were presented simultaneously in a list in descending order against 10/10 sexual activity in the future. There were 6 levels of delay until the future reward [1, 2, 6, 24, 48, 72] hours. At the beginning of the sex-discounting task, participants were asked "when was the last time you had sexual activity?" (less than 24 h ago, 1 day > 4 days ago, 4 > 7 days ago, 2 weeks ago, more than 2 weeks ago, prefer not to say), but the responses were not analysed.

Analyses

Because our primary outcome measure (discounting behaviour) is a count (number of immediate choices selected) out of n total choices, then the relevant form of generalized linear modelling is binomial regression with a logistic link function. The likelihood function is therefore $y_i \sim Binomial(n, \epsilon + (1 - 2\epsilon) \cdot InverseLogistic(\mu_i))$, which can be thought of as describing the probability of having observed y_i "successes" (i.e. immediate choices) for participant i, out of n trials. InverseLogistic(μ_i) is the probability of success, where μ_i is the output of a linear model. The inverse logistic function corresponds to a logistic link function and maps to the range 0–1, which is valid for probabilities. The term $\epsilon + (1 - 2\epsilon)$ implements a "lapse rate" which limits the

probability of observing immediate choices to a minimum of ϵ and a maximum of $1 - \epsilon$ (where we set $\epsilon = 0.01$). This is a commonly used method to avoid data being seen as infinitely unlikely if the model predicts probabilities of 0 or 1.

For the categorical analysis by menstrual phase, the linear model is $\mu_i = \beta[phase_i]$ where β is a vector of 3 values (one for each group) and $phase_i$ indexes into the appropriate group that participant i is in. For the quadratic binomial regressions of discounting as a function of days since onset, we have $\mu_i = \beta_0 + \beta_1 days_i + \beta_2 days_i^2$. For evaluating discounting as a function of fertility, we use a linear model for the NC women, $\mu_i = \beta_0 + \beta_1 fertility_i$. And for the HC women, we fit an intercept-only model, $\mu_i = \beta_0$, because fertility is held approximately constant. We used Normal priors over the β parameters, centred on zero with high standard deviations as the data were not z-scored. This means the priors were broadly uninformative, meaning that the resulting posterior distributions over regression coefficients are primarily determined by the data.

We conducted Bayesian binomial regressions, evaluating the posterior distributions over the model parameters given the observed data, $P(\beta|x, y)$ where x is either the phase, fertility score, or days since onset, and y is the number of immediate choices made (for either money, food, or sex rewards). Practically, these posterior distributions were evaluated in Python using PyMC3 (Salvatier et al., 2016), and analysis and plotting was aided by the ArviZ package (Kumar et al., 2019). All analysis code is available in online supplementary material (see Appendix).

Because this study was largely exploratory in nature, we conduct *parameter estimation*, reporting posterior beliefs (posterior means and 95% credible intervals) about effect sizes as opposed to explicit *hypothesis testing* via Bayes Factors (interested readers are referred to Kruschke, 2011). Note that 95% *credible* intervals correspond to range that we believe has 95% chance of containing the true effect size, unlike Frequentist 95% *confidence* intervals.

Results

Descriptive Statistics

The participant composition, after exclusion, is shown in Table 2. The menstrual cycle lengths reported had a bimodal distribution, indicating that some participants reported duration of menstruation and the majority reporting length of the menstrual cycle — we do not use this variable as a predictor, nor for exclusion, and do not analyse it further. The mean number of days bleeding reported was 5.2, with a standard deviation of 1.8 days — there was one outlier who reported 28 days bleeding, who was not excluded. The majority of women 167 (55.3%) tracked their menstrual cycle with an

Table 2 Demographic characteristics for the whole sample ($N = 302$)

Trait	Category	Number, proportion
Sexuality	Heterosexual	227, 75.2%
	Bisexual	46, 15.2%
	Homosexual	10, 3.3%
	Asexual	9, 2.8%
	Unsure	5, 1.7%
	Prefer not to say	5, 1.7%
Relationship status	Serious	138, 45.7%
	Single	88, 29.1%
	Married	60, 19.9%
	Casual	16, 5.3%
Relationship types	Monogamous	271, 89.7%
	Prefer not to say	8, 2.7%
	Open relationship	3, 1%
	Polyamorous	3, 1%
	Polygamous	2, 0.7%
Ethnicity	Caucasian	257, 85.1%
	Asian	16, 5.3%
	Prefer not to say	12, 4%
	Mixed	9, 3%
	Black/African/Caribbean	8, 2.7%
Gender identity	Female	296, 98%
	Non-binary	3, 1%
	Male	2, 0.66%
	Prefer not to say	1, 0.33%
Menstruation regularity	Perfectly regular	83, 27.5%
	Regular (2–4-day difference)	192, 63.6%
	Irregular (5–7-day difference)	27, 8.9%

app, 51 (16.9%) used a calendar, and 11 (3.6%) used a range of other methods, while 73 (24.2%) did not use any tracking method. The mean reported BMI was 24.5 (median of 23.7) with a standard deviation of 5.6 kg/m^2.

Exploratory Results

We examined whether we could replicate the results of Lucas and Koff (2017) for monetary rewards and whether this result generalised to food and sex commodities. Figure 1 (top) shows mean discounting behaviour as a function of ovulatory cycle phase. Because we are not interested in comparing discounting behaviour across commodities, 3 independent Bayesian binomial regression models were used to estimate the mean number of immediate rewards chosen for each phase. We used the same method of calculating ovulatory phase as Lucas and Koff (2017): Early Follicular: ≤ 7 days since onset; Late Follicular: 8–15 days since onset; Luteal: 16–28 days since onset. Figure 1 (top row) shows a common pattern across all 3 commodities — the proportion of immediate choices increases in the fertile LF phase which then partially drops back down in the LP. Posterior distributions indicate unambiguous evidence of increases in the proportion of immediate choices from EF to LF (Fig. 1, middle row). The Cohen's h effect sizes for

money (0.12, CI$_{95\%}$: 0.064, 0.17), food (0.15, CI$_{95\%}$: 0.095, 0.20), and sex (0.37, CI$_{95\%}$: 0.32, 0.43) are "small" (Cohen, 1988). Posterior distributions of effect sizes from LF to LP (Fig. 1, bottom row) also show strong evidence for a slight decrease, but not a return to levels in EF. Cohen's h effect sizes are "small" for money (-0.061, CI$_{95\%}$: $-0.11, -0.011$), food (-0.099, CI$_{95\%}$: $-0.15, -0.048$), and sex (-0.14, CI$_{95\%}$: $-0.19, -0.085$).

Confirmatory Results

While converting days since menstrual onset into categorical phases is common, it does discard information about where women are within that phase. We build upon the previous results with the hope of gaining further insight into the time-course of discounting changes over the menstrual cycle.

Discounting as a Function of Days Since Onset In our first pre-registered analysis, we tested for non-linear relationships of discounting as a function of days since onset. Figure 2 shows the results of our quadratic binomial regression analyses. The lines and shaded regions show the posterior mean and 95% credible intervals in the mean probability of choosing the immediate rewards. These clearly demonstrate quadratic relationships in all cases — an observation
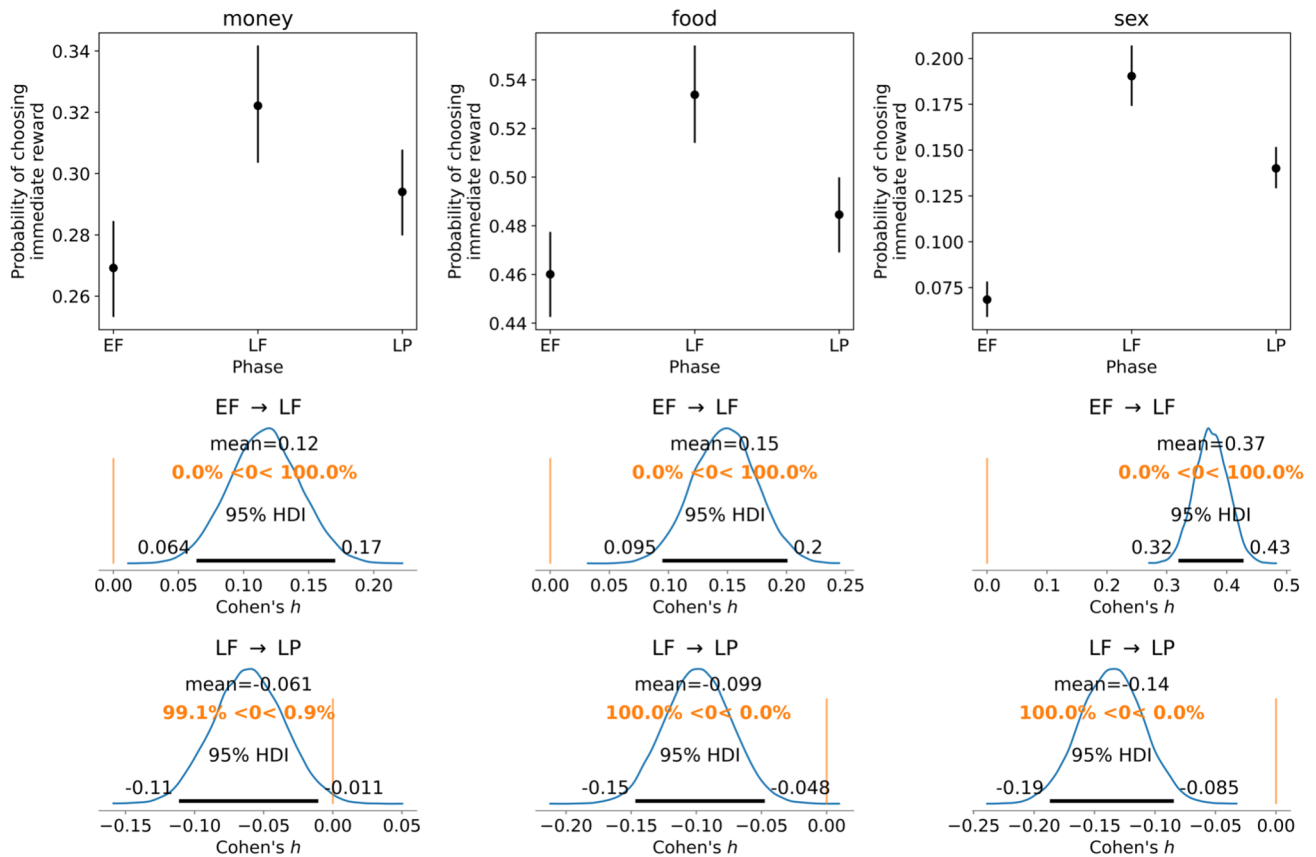
Fig. 1 Mean discounting behaviour for naturally cycling (NC) women grouped by phase of the ovulatory cycle, for each of the 3 commodities (top row). The y-axis represents the probability of choosing immediate rewards as computed through Bayesian binomial regres-

sion. For example, a value of 0.2 equates to 20%. Error bars represent 95% Bayesian credible intervals. Distribution plots (middle, bottom rows) show posterior distributions over the effect size, Cohen's h. Mean and 95% credible intervals are rounded to 2 significant figures

supported by the posterior distributions of regression coefficients being credibly non-zero (see Table 3) for all linear and quadratic terms. That is, none of the 95% credible intervals overlap with zero. All the intercept terms β_0 were also credibly non-zero, although this is less theoretically interesting as β_0 is simply the intercept term which shifts the baseline proportion of immediate choices up or down.

Discounting as a Function of Fertility Having found evidence for change in discounting over the cycle, we test the idea that this can (at least in part) be accounted for by changes in fertility over the cycle. So our second pre-registered analysis explored linear relationships between discounting behaviour and fertility (see Fig. 3). If fertility is an important factor, then we would expect to find a linear relationship between fertility and discounting behaviour for NC women. This would not apply to HC women, whose fertility is held approximately constant over time. Figure 3 shows intercept fits to HC women and linear regression fits to NC women. The posterior distributions over the slope parameter for the NC women are all credibly positive: for money it is 2.00,

$CI_{95\%}$: 0.89, 3.18, for food it is 2.15, $CI_{95\%}$: 1.11, 3.34, for sex it is 5.48, $CI_{95\%}$: 4.08, 6.85. We calculated the Cohen's h effect sizes comparing the probability of choosing the immediate reward at the lowest and highest fertility levels, resulting in small effect sizes for money (0.075), food (0.069), and sex (0.075).

Discussion

The present study aimed to address three questions. Firstly, we explored whether cycle phase (EF, LF, LP) influences delay discounting across the food, sex, and money commodities in NC women (see Fig. 1). Secondly, by assessing non-linear trends over the cycle for both NC and HC women, we found evidence for a quadratic trend for all commodities and both groups (see Fig. 2). For the NC group, immediate choices increased from the EF to the LF (when most fertile) and then decreased to the LP across all commodities. The same pattern occurred for the HC group for money and food; however, the opposite pattern was shown for sex. Thirdly,

Fig. 2 Mean discounting behaviour as a function of days since onset for naturally cycling (NC) and hormonal contraception (HC) groups, resulting from Bayesian quadratic binomial regression analyses. Solid lines represent posterior means, and the shaded regions represent 95% credible intervals in the mean probability of choosing the immediate reward. Note: the functions may not look exactly quadratic because the quadratic term is passed through the inverse logistic function to constrain probabilities between 0 and 1
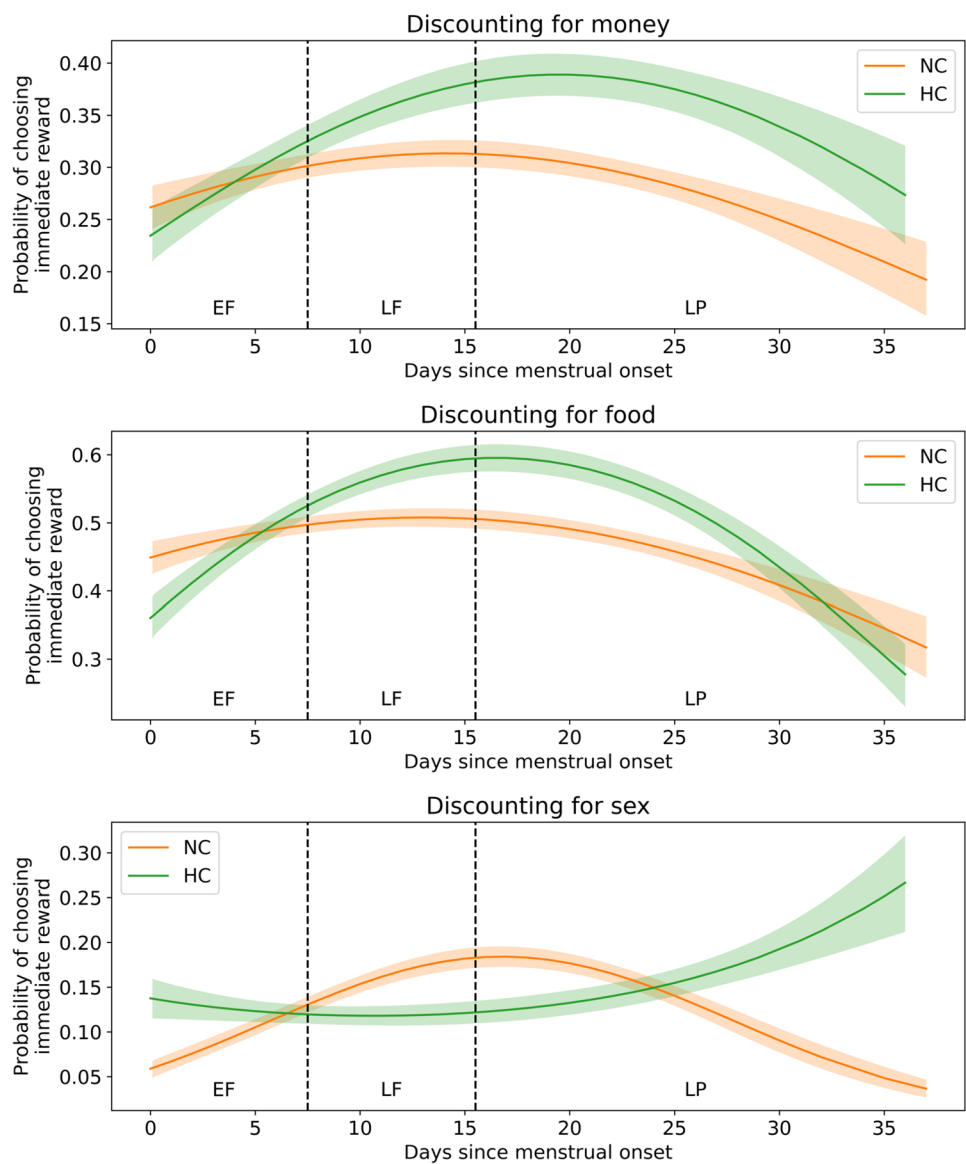
we explored whether change in discounting across the cycle could (at least partially) be explained by changes in fertility. This does seem to be the case, as NC women showed a linear increase in immediate choices across all commodities as a function of fertility (see Fig. 3).

The results summarised in Fig. 1 are in line with those of Lucas and Koff (2017). Similar to Lucas and Koff's (2017) results, the probability of choosing immediate rewards increased from the EF to the LF, followed by a drop again in the LP; however, in contrast to their findings, they remained somewhat elevated compared to the EF phase. Our results go further, however, in that we show this pattern of behaviour generalises across all the commodities tested — money, food, and sex. The present findings did contradict the finding of lower preference for immediate monetary rewards near ovulation (Smith et al., 2014). Although they used hormonal

assays to determine cycle phase which is more robust than the count-back method used in the present study, the authors only took measures on 2 days. The findings of the present study match those of Lucas and Koff (2017) which measured day of cycle at multiple timepoints.

Discounting for money, food, and sex changes over the menstrual cycle for NC women, with more immediate choices being made on average around the most fertile LF phase (see Fig. 2), is in line with the ovulatory shift hypothesis. NC individuals would theoretically be expected to optimise resources and immediate choices when conception is at a higher risk (da Matta et al., 2013; Gildersleeve et al., 2014). Additionally, there was support that some of the variation in discounting behaviour in NC women over the menstrual cycle can be attributed to fertility (see Fig. 3). Women who are NC are, on average, more likely to choose

Table 3 Summary statistics of the posterior distributions over all (unstandardised) regression coefficients for the quadratic binomial regressions shown in Fig. 2. Plots of the posterior distributions of all parameters are available in the online Supplementary Materials. HDI = highest density intervals

| Parameter	Group	Commodity	Mean	SD	Lower 95% HDI	Upper 95% HDI
β_0	HC	Money	− 1.216	0.075	− 1.360	− 1.067
β_0	HC	Food	− 0.587	0.069	− 0.722	− 0.451
β_0	HC	Sex	− 1.904	0.104	− 2.109	− 1.705
β_0	NC	Money	− 1.064	0.056	− 1.175	− 0.953
β_0	NC	Food	− 0.210	0.051	− 0.309	− 0.110
β_0	NC	Sex	− 2.951	0.100	− 3.140	− 2.748
β_1	HC	Money	0.077	0.011	0.056	0.099
β_1	HC	Food	0.119	0.010	0.099	0.141
β_1	HC	Sex	− 0.035	0.015	− 0.066	− 0.007
β_1	NC	Money	0.037	0.009	0.020	0.053
β_1	NC	Food	0.037	0.008	0.022	0.052
β_1	NC	Sex	0.169	0.014	0.141	0.197
β_2	HC	Money	− 0.002	0.000	− 0.003	− 0.001
β_2	HC	Food	− 0.004	0.000	− 0.004	− 0.003
β_2	HC	Sex	0.002	0.000	0.001	0.003
β_2	NC	Money	− 0.001	0.000	− 0.002	− 0.001
β_2	NC	Food	− 0.001	0.000	− 0.002	− 0.001
β_2	NC	Sex	− 0.005	0.000	− 0.006	− 0.004

immediate rewards at more fertile points in their cycle. NC women should choose immediate rewards at peak fertility, especially sex, as they would be anticipating offspring. Biologically, we know that hormone levels during this point lead to increased impulsivity which is consistent with this result (Diekhof, 2015). The finding of preference for food increasing with fertility contradicts those by Fessler (2003) who reported a decrease in calorie consumption with fertility. However, this could be the result of the present study utilising discounting measures which represent a preference and do not necessarily translate to behaviour. For medium-/ high-fertility levels, NC women are more likely to choose immediate lower-quality sex than HC women. This inspires the hypothesis that because HC bodies are more hormonally similar to pregnancy than NC bodies, perhaps higher-quality sex may be preferred as a method of partner bonding over an immediate but low-quality opportunity for intercourse and conception.

Interestingly, HC women discount more for money and food, only matched by NC women at peak fertility. The rise and fall of immediate choices for money and food were even more exaggerated compared to NC women. Most hormonal contraceptives function through simulating pregnancy. Therefore, HC individuals would need resources for offspring. Again, biologically this is plausible as HC hormone levels are most similar to the fertile point of the cycle. The exception to the above was discounting of sex by HC women. The probability of choosing immediate low-quality sex over delayed high-quality sex seemed to be approximately stable but with an increase toward the end of the menstrual cycle. This could be noise that may disappear in a

study with more participants or using a longitudinal design. If not, a speculative hypothesis (to be tested in a future study) would be that it represents a desire to have sex before the next menstrual period begins. Given that there is no risk of conception to HC individuals, they may be opportunistically choosing intercourse later in the cycle (LP) to avoid having intercourse during menstruation. Vaginal intercourse during menstruation has medical implications, including an increased risk of sexually transmitted infections (STIs) and endometriosis (Mazokopakis & Samonis, 2018). Another plausible explanation for this result could be that HC can lead to increased libido as it improves PMS and studies have shown increased female-initiated activity later in the pill cycle (LP; Guillebaud, 2017). The quadratic trends seen within the HC group were unexpected, and although hypotheses can be speculated, there is a need for future research to consider the mechanisms underlying these findings, and whether HC type has a role.

Additionally, not comparing different types of HC is problematic as the different types have varying hormonal effects (Hampson, 2020). Further studies should include an HC sample when investigating the menstrual cycle and account for the type and duration of contraceptive use. Both the present study and Lucas and Koff (2017) used cross-sectional designs which is problematic as menstrual cycles vary between females and as such a within-subject design would be beneficial for future research. While the Cohen's h effect sizes are "small", this should be interpreted with extreme caution — they are entirely unlike Cohen's d effect sizes, taking no account of the difference normalised by the degree of variance, nor the sample size.

Fig. 3 Mean discounting behaviour as a function of fertility for naturally cycling (NC) and hormonal contraception (HC) groups, obtained from Bayesian binomial regression models. NC women were fitted with a slope and intercept model while HC women were fitted with an intercept only model, as fertility is held constant in the HC group
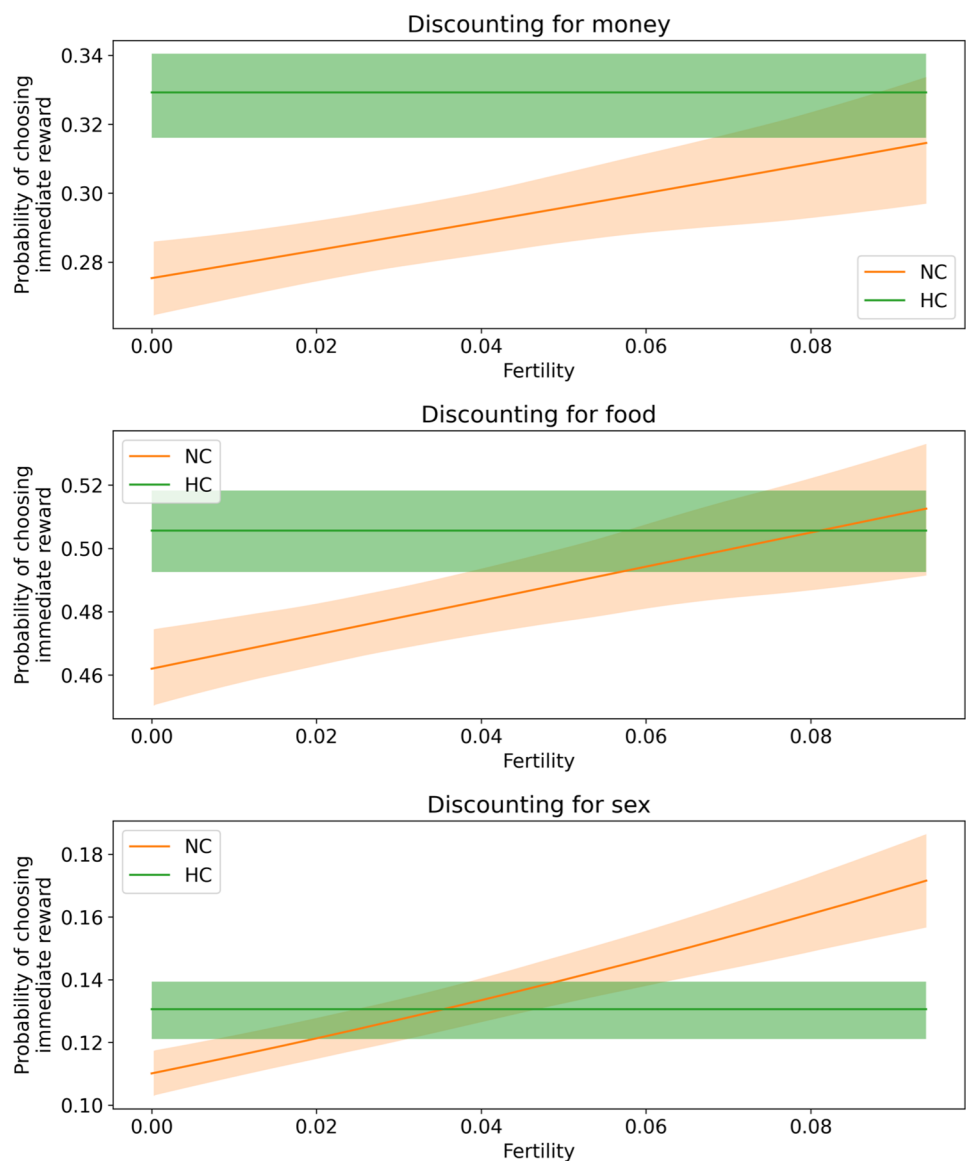
As such, in the context of delay discounting, a change from ~ 7.5 to ~ 20% immediate low-quality over delayed high-quality sex choices (see Fig. 1, top right) could be considered as a behaviourally meaningful change. We do not make strong claims based on our data about the exact shape of this change over the menstrual cycle, nor about the location of the peak of immediate choices. The present study used quadratic regression which has been used before in tracking how variables change over the menstrual cycle (Kuukasjärvi et al., 2004). Future research should continue with this non-linear form of analysis over days (not categorical phases) to encompass changes across the menstrual cycle phases as other analyses may fail to capture its cyclical nature.

Conclusion

Within-participant longitudinal designs would provide higher statistical power in the study of behaviour change over the menstrual cycle by controlling for individual variation in baseline discounting behaviour (Warren et al., 2021). That said, while prior evidence was mixed, our findings from 203 NC and 99 HC women demonstrate that changes in discounting behaviour can be detected in a cross-sectional study design. By analysing how discounting changed (using a quadratic model) over the menstrual cycle and including HC women as a control group, we found evidence for changes in discounting behaviour over the menstrual cycle in both groups. Some

of this variation over the menstrual cycle in NC women can be accounted for by the rise and fall in fertility, consistent with evolutionary shift hypotheses (Gangestad et al., 2005; Gildersleeve et al., 2014). Future studies could refine the precise time course of these changes over the menstrual cycle and examine if behaviour change differs by type of hormonal contraception.

Author Contribution Benjamin T. Vincent and Mariola Sztwiertnia contributed to the study design. Questionnaire design and data collection were performed by Mariola Sztwiertnia. Data analysis was performed by Benjamin T. Vincent. All authors contributed to the writing of the manuscript. All authors read and approved the final manuscript.

Declarations

Ethics Approval The study received ethical approval from the University Research Ethics Committee of the University of Dundee.

Consent to Participate Informed consent was obtained from all individual participants included in the study.

Consent for Publication Not applicable.

Competing Interests The authors declare no competing interests.

References

Andersen, S., Harrison, G. W., Lau, M. I., & Rutström, E. E. (2006). Elicitation using multiple price list formats. *Experimental Economics, 9*(4), 383–405. https://doi.org/10.1007/s10683-006-7055-6

Anwyl-Irvine, A. L., Massonnié, J., Flitton, A., Kirkham, N., & Evershed, J. K. (2020). Gorilla in our midst: An online behavioral experiment builder. *Behavior Research Methods, 52*(1), 388–407. https://doi.org/10.3758/S13428-019-01237-X/TABLES/8

Cantú, S. M., Simpson, J. A., Griskevicius, V., Weisberg, Y. J., Durante, K. M., & Beal, D. J. (2014). Fertile and selectively flirty: Women's behavior toward men changes across the ovulatory cycle. *Psychological Science, 25*(2), 431–438. https://doi.org/10.1177/0956797613508413

Charlton, S. R., & Fantino, E. (2008). Commodity specific rates of temporal discounting: Does metabolic function underlie differences in rates of discounting? *Behavioural Processes, 77*(3), 334–342. https://doi.org/10.1016/J.BEPROC.2007.08.002

Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences (2nd ed.). Lawrence Erlbaum Associates.

da Matta, A., Gonçalves, F. L., & Bizarro, L. (2013). Delay discounting: Concepts and measures. *Psychology & Neuroscience, 5*(2), 135. https://doi.org/10.3922/J.PSNS.2012.2.03

Diekhof, E. K. (2015). Be quick about it. Endogenous estradiol level, menstrual cycle phase and trait impulsiveness predict impulsive choice in the context of reward acquisition. *Hormones and Behavior, 74*, 186–193. https://doi.org/10.1016/J.YHBEH.2015.06.001

Durante, K. M., Griskevicius, V., Cantú, S. M., & Simpson, J. A. (2014). Money, status, and the ovulatory cycle: *Journal of Marketing Research, 51*(1), 27–39. https://doi.org/10.1509/JMR.11.0327

Durante, K. M., Griskevicius, V., Hill, S. E., Perilloux, C., & Li, N. P. (2011). Ovulation, female competition, and product choice: Hormonal influences on consumer behavior. *Journal of Consumer Research, 37*(6), 921–934. https://doi.org/10.1086/656575/0

Erol, A., & Karpyak, V. M. (2015). Sex and gender-related differences in alcohol use and its consequences: Contemporary knowledge and future research considerations. *Drug and Alcohol Dependence, 156*, 1–13. https://doi.org/10.1016/J.DRUGALCDEP.2015.08.023

Fessler, D. M. T. (2003). No time to eat: An adaptationist account of periovulatory behavioral changes. *Quarterly Review of Biology, 78*(1), 3–21. https://doi.org/10.1086/367579

Gangestad, S. W., Thornhill, R., & Garver-Apgar, C. E. (2005). Adaptations to ovulation: Implications for sexual and social behavior. *Current Directions in Psychological Science, 14*(6), 312–316. https://doi.org/10.1111/J.0963-7214.2005.00388.X

Gildersleeve, K., Haselton, M. G., & Fales, M. R. (2014). Do women's mate preferences change across the ovulatory cycle? *A Meta-Analytic Review. Psychological Bulletin, 140*(5), 1205–1259. https://doi.org/10.1037/A0035438

Guillebaud, J. (2017). *Contraception: Your questions answered*. Elsevier Health Sciences.

Hampson, E. (2020). A brief guide to the menstrual cycle and oral contraceptive use for researchers in behavioral endocrinology. *Hormones and Behavior, 119*, 104655. https://doi.org/10.1016/J.YHBEH.2019.104655

Haselton, M. G., Mortezaie, M., Pillsworth, E. G., Bleske-Rechek, A., & Frederick, D. A. (2007). Ovulatory shifts in human female ornamentation: Near ovulation, women dress to impress. *Hormones and Behavior, 51*(1), 40–45. https://doi.org/10.1016/J.YHBEH.2006.07.007

Kruschke, J. K. (2011). Bayesian assessment of null values via parameter estimation and model comparison. *Perspectives on Psychological Science, 6*(3), 299–312. https://doi.org/10.1177/1745691611406925

Kumar, R., Carroll, C., Hartikainen, A., & Martin, O. (2019). ArviZ a unified library for exploratory analysis of Bayesian models in Python. *Journal of Open Source Software*, *4*(33), 1143. https://doi.org/10.21105/JOSS.01143

Kuukasjärvi, S., Eriksson, C. J. P., Koskela, E., Mappes, T., Nissinen, K., & Rantala, M. J. (2004). Attractiveness of women's body odors over the menstrual cycle: The role of oral contraceptives and receiver sex. *Behavioral Ecology, 15*(4), 579–584. https://doi.org/10.1093/BEHECO/ARH050

Lucas, M., & Koff, E. (2013). How conception risk affects competition and cooperation with attractive women and men. *Evolution and Human Behavior, 34*(1), 16–22. https://doi.org/10.1016/J.EVOLHUMBEHAV.2012.08.001

Lucas, M., & Koff, E. (2017). Fertile women discount the future: Conception risk and impulsivity are independently associated with financial decisions. *Evolutionary Psychological Science 2017 3:3, 3*(3), 261–269. https://doi.org/10.1007/S40806-017-0094-8

Mazokopakis, E. E., & Samonis, G. (2018). Is vaginal sexual intercourse permitted during menstruation? A biblical (Christian) and medical approach. *Mædica*, *13*(3), 183. https://doi.org/10.26574/MAEDICA.2018.13.3.183

Periods and fertility in the menstrual cycle - NHS. (2019). https://www.nhs.uk/conditions/periods/fertility-in-the-menstrual-cycle/

Rosati, A. G., & Hare, B. (2016). Reward currency modulates human risk preferences. *Evolution and Human Behavior, 37*(2), 159–168. https://doi.org/10.1016/J.EVOLHUMBEHAV.2015.10.003

Saad, G., & Stenstrom, E. (2012). Calories, beauty, and ovulation: The effects of the menstrual cycle on food and appearance-related consumption. *Journal of Consumer Psychology, 22*(1), 102–113. https://doi.org/10.1016/J.JCPS.2011.10.001

Salvatier, J., Wiecki, T., & v., & Fonnesbeck, C. (2016). Probabilistic programming in Python using PyMC3. *PeerJ Computer Science, 2016*(4), e55. https://doi.org/10.7717/PEERJ-CS.55/FIG-7

Smith, C. T., Sierra, Y., Oppler, S. H., & Boettiger, C. A. (2014). Ovarian cycle effects on immediate reward selection bias in humans: A role for estradiol. *Journal of Neuroscience, 34*(16), 5468–5476. https://doi.org/10.1523/JNEUROSCI.0014-14.2014

Thornhill, R., & Gangestad, S. W. (2008). *The evolutionary biology of human female sexuality*. Oxford University Press. https://www.amazon.co.uk/Evolutionary-Biology-Human-Female-Sexuality/dp/019534099X

Wallen, K., & Zehr, J. L. (2004). Hormones and history: The evolution and development of primate female sexuality. *Journal of Sex Research, 41*(1), 101. https://doi.org/10.1080/00224490409552218

Warren, J. G., Goodwin, L., Gage, S. H., & Rose, A. K. (2021). The effects of menstrual cycle stage and hormonal contraception on alcohol consumption and craving: A pilot investigation. *Comprehensive Psychoneuroendocrinology, 5*, 100022. https://doi.org/10.1016/J.CPNEC.2020.100022

Wilcox, A. J., Dunson, D. B., Weinberg, C. R., Trussell, J., & Day Baird, D. (2001). Likelihood of conception with a single act of intercourse: Providing benchmark rates for assessment of postcoital contraceptives. *Contraception, 63*, 211–215.